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CAPIR/DEM - A COLLECTION SYSTEM FOR GEOGRAPHICALLY
BASED DIGITAL ELEVATION DATA FOR ARMY ENGINEER
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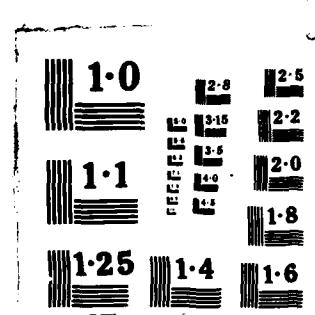
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CAPIR/DEM - A COLLECTION SYSTEM
FOR GEOGRAPHICALLY BASED DIGITAL ELEVATION DATA

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ABSTRACT

A collection system for digital elevation models (DEMs) using an adaptive spacing grid with an analytical plotter is discussed. The adaptive spacing grid is used to optimize resources when collecting DEMs in areas that have wide variations in relief. The collection system is used to collect DEMs for emerging technologies such as robotics, computer image generation, and computer simulation. Future enhancements are proposed to provide adjustments between data collected during separate sessions and to densify existing DEM data to a higher resolution. *Keywords: DEM (Digital Elevation Model), Robotics, Computer, Image Generation, Photogrammetry, Correlators.*

INTRODUCTION

Digital grid-point elevation models (DEMs) are a widely distributed and applied source of digital topographic data. DEMs are commonly used to generate planimetric contour, slope, or aspect maps and are often merged with other sources of data for sophisticated modeling and systems applications. DEMs either cover large land areas at a coarse resolution or cover very limited sites at high resolution. Emerging technology in such diverse areas as robotics, computer image generation, and computer simulation will require timely, cost effective custom DEM data. The development described in this paper details a system designed to meet these impending future requirements for DEM (Digital Elevation Model).

The compilation of DEM data is a tractable problem. Grid elevation data can be compiled from maps, photogrammetric plotters and automated photo correlators. DEMs also contain data in a form readily manipulated by computer processing techniques.

However, DEMs have two less favorable aspects. First, elevation models do not accurately represent the continuous physical topographic expression of the ground surface. Variations in relief will be missed as a function of the size and uniformity of the horizontal sampling resolution. This resolution is rarely determined by the frequency of topographic variation, but is instead at a uniform interval unrelated to the ground disparity. Second, the process of DEM compilation is prone to error. DEM compilation from digitization of map elevation

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contours is limited by the accuracy of the cartographic representation and the resulting polygon-to-grid interpolation. Elevation compilation from stereo aerial photos in a photogrammetric plotter promises high accuracy, but is constrained by human factors related to the redundancy of the task and equipment limitations. DEM production using automated stereo correlation is a promising area for research and development, particularly when employing operations based on a priori knowledge and rule-based constraints. However, current systems can not provide the vertical accuracy needed to support coming advanced applications.

New techniques and systems are required to meet emerging technologies. The system described in this paper was developed to support part of the digital terrain data base compilation for the DARPA Autonomous Land Vehicle Program (ALV).

ALV AND CAPIR

The DARPA Strategic Computing Program is a large, multi-year effort focused on developing the next generation of computers and machine intelligence. Within this program the Autonomous Land Vehicle Project calls for the development and demonstration of increasingly sophisticated autonomous robotic land vehicle travel and navigation. This initiative requires the merging of diverse technologies to accomplish program goals. These technologies include: machine vision, sensor engineering, artificial intelligence, advanced computing systems, and digital topography. As part of this effort, the U.S. Army Engineer Topographic Laboratories (USAETL) has the task of producing a high resolution, high accuracy experimental digital terrain data base of a 16 square kilometer test site. This data base will be used in conjunction with an inertial navigation system within the ALV. The data base will initially consist of the following themes: landform, surface drainage, soil, landcover, roads, and a DEM at five meter spacing. ALV applications of the terrain data base include pre-mission route planning, operational context, and a priori information for machine vision. It is expected that ALV will lead to future data base revisions.

Compilation of this data base is being performed on the Computer-Assisted Photo Interpretation Research (CAPIR) system at USAETL. CAPIR is an ongoing research effort which addresses the issues of digital terrain data extraction, storage, and exploitation. This integrated system consists of a mini-computer based geographic information system controlling an analytical plotter equipped with stereo graphics superposition to provide the mechanism for three-dimensional capture, verification, and management. The unique requirements of the ALV program led to the development of the CAPIR DEM system to permit compilation of a custom digital elevation model.

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SYSTEM DEVELOPMENT REQUIREMENTS

DEM system development requirements were formulated based on both the need to support the ALV project, and also future programs and internal research. Compilation would need to be based on geodetic spacing. Sampling resolution must provide for a variable horizontal collection spacing of approximately .1 meter to a maximum limited only by source imagery. Project ground coverage would provide for any geographically rectangular area and permit DEM compilation from any number of stereo models.

Sampling rates would be uniform within a specified collection area or group, but varied between collection areas based on the frequency of topographic relief and the intended data application. Subsequent interpolation between groups of varied DEM density would be required. Disparities due to each interior orientation model setup would need to be recorded and individual collection areas would be overlapped to provide statistical analysis which might be used in an adjustment of collection areas if necessary.

System Design Considerations

Given the requirements and goals of the system, the CAPIR DEM design goal was to produce a system which accomplished the bookkeeping chores necessary to support an adaptive spacing grid, while at the same time, did not prove cumbersome during the compilation of elevation data. This goal has been functionally implemented by requiring a group of set-up functions to be completed before compilation of elevation data can begin.

These set-up functions provide a "mapping" between the various conceptual layers of information in the CAPIR DEM system (Figure 1). The first layer of information to be mapped is the stereomodel layer. This layer represents the photographic coverage of stereomodels over the project area. The subcell layer is an even-interval grid defined by the smallest integer evenly divisible by each of the sampling densities specified during the set-up procedures. The group layer defines the adaptive spacing grid to be used in the DEM collection. The group layer associates subcells within which a common sampling interval will be used. Finally, the DEM layer represents the measured elevations associated at a particular latitude/longitude.

Once the set-up functions are completed, the analyst is responsible for ensuring the accuracy of the Z-elevation, while the hardware and software accounts for the positioning of the X and Y locations. Compilation proceeds in this fashion until the entire stereo model is sampled, at which time another model could be established and collection could continue.

This design strategy has proven useful during the design and development of the CAPIR DEM system. As the following section illustrates, the system provides the functionality needed to accomplish the system requirements.

DEM LAYER REPRESENTS MEASURED ELEVATION AT VARIOUS INTERVALS.

GROUP LAYER ASSEMBLAGES OF SUBCELLS WITHIN WHICH ALL SAMPLES ARE COLLECTED AT A COMMON SAMPLING INTERVAL

SUBCELL LAYER REPRESENTS THE LARGEST OF THE SAMPLING INTERVALS CHOSEN FOR THE PROJECT.

STEREO MODELLAYER REPRESENTS THE COVERAGE OBTAINABLE FROM EXISTING PHOTOGRAPHY.

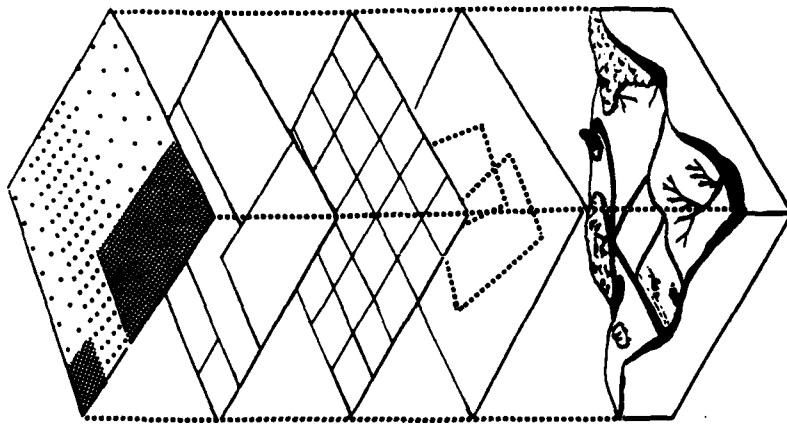


Figure 1. Layers of abstraction in CAPIR/DEM system

CAPIR DEM Functionality

This section presents an overview of the various functions of CAPIR DEM.

Project Setup. Project setup is the initial function performed by the operator using the CAPIR DEM system. This function defines the geographic area from which DEM information will be extracted. The CAPIR DEM system prompts the operator for the geographic bounds for the area in degrees, minutes, and seconds with the Southern and Western hemispheres considered to have negative values for latitude and longitude, respectively. An additional purpose of this function is to ascertain from the operator the particular ellipsoid to be used for internal imagery to geographic coordinate transformations.

DEM Setup Operations. The DEM setup operations prompt the operator for DEM collection parameters which determine or limit all subsequent DEM collection characteristics. The characteristics determined by these operations are:

- 1) units of measure for the sampling intervals (arc-seconds, nominal meters, nominal feet)
- 2) units of measure for the sample elevations (meters, feet)
- 3) the actual values for the sampling intervals
- 4) subcell size

Sampling interval units of measure can be in any one three forms: arc-second, nominal meters, or nominal feet. Arc second measure follows the geographic grid for the entire project area, is in units consistent with the geographic grid, and as a result is accurate for the entire project area (within the constraints of double precision real values). Nominal meter and feet values are internally transformed into arc second values at the project area center, and as a result, direct correspondence exists only at the project center due to the compromising affects of meridional convergence and the Earth's eccentricity. Meridional convergence results in an east-west shift of approximately one meter at the corners of a project area 4 km by 4km in extent and located at 40 degrees north latitude (as compared to a Cartesian grid with origin at the project center). Sample elevation units of measure are restricted to meters or feet and are internally stored as single precision real values. Sampling interval values are selected as a "set" by the operator and are not restricted by the software. However, small sampling interval values for large project areas are to be avoided as very large data files will result, possibly exhausting all disk storage on the computer system. Subcell size units of measure are determined by selection of the units of measure for the sampling intervals. Subcell size value is limited to being an integer multiple of the largest sampling interval value and fitting within the project area. The operator can have a graphic display superimposed over the

photography using the Graphics Superposition hardware to assist in the selection of subcell size (and indirectly the selection of sampling interval values).

Due to the importance of the operations described above, the CAPIR DEM system echoes the units of measure and the particular values chosen for a given characteristic. To preserve the integrity of the DEM data base, the selection for DEM setup operations characteristics can not be altered after being approved by the operator. Once the DEM setup operations have been completed, the analyst can perform a stereo model setup function.

Model Setup. The model setup option is used to register a stereo model on the analytical plotter, and to create and download stereo maintenance tables to automatically keep the two photographs in stereo throughout all other functions of the CAPIR DEM system.

The registration procedure is performed by prompting the user to visit and measure four fiducial marks on each photograph with the analytical plotter. The fiducialing process defines the orientation of the photographs on the stages of the analytical plotter. In addition, this process describes the transformation from each stage coordinate system into a fiducial system for that stage. After the user has measured the fiducials on one stage, residuals are reported and the user is able to remeasure the fiducials until the desired accuracy is achieved for each photo.

After the fiducials have been measured, a known ground point must be measured. A previously entered accuracy criteria must be met when measuring the checkpoint, or the software will not allow the operator to continue. If the checkpoint accuracy criteria is not met, the operator may remeasure the checkpoint, remeasure the fiducials, or restart the entire model set up process.

Group Definition. The concept of groups is important within the CAPIR DEM system. The group is defined as that area in which all sampling is performed in a uniform spacing, while samples in areas adjacent to this group may be sampled at different sampling intervals. Groups are used to allow the analyst to define such homogenous regions of sampling density based upon the terrain variables which exist within a group of subcells.

The selection of groups in the CAPIR DEM system is a repeatable function which is initiated after DEM setup functions have been completed. The analyst associates a group of subcells with a particular sampling reference frame by positioning the analytical plotter to the bounding subcells for that group. Subcells within the group are then flagged with this sampling density.

Compilation/Editing. Compilation of elevation data begins after DEM setup functions have been completed, after the model has been set up, and after all control

points have been entered. After compilation begins, control points cannot be modified since to do so would jeopardize the accuracy of previously determined measurements.

Once the analyst has met the set up requirements, a collection window must be defined. The collection window is the area in which the analyst will collect elevation information in one sitting. After the analyst defines a collection window, the software determines the subcells within the collection window and the groups associated sampling densities which are within the window.

The analytical plotter then vectors to the first valid sample within the collection window. Samples are automatically taken within a profile that is within the group and within the collection window. Once all samples have been collected within the group and within the collection window, the analytical plotter vectors to the next group until all samples within all groups of the collection window have been sampled.

Stereo Graphics Superposition Software Functionality. The graphics superposition display provides essential operator assistance in the compilation of DEM information for a geographic area. This assistance has two functions. First, interactive graphic feedback delineating and defining the geographic study area. Secondly, interactive graphic feedback identifying post points at measured geographic location and elevation. Interactive graphic feedback is provided to the operator in the following forms:

- 1) For a given stereo model the bounding quadrilateral can be displayed three-dimensionally, offering the operator a check on those portions of the study area within or outside the given model.
- 2) The outlines of the subcells are displayed in three-dimensionally at correct geographic location offering the operator a visual check on the suitability of a given subcell size to adequately and efficiently subdivide the study area, that is, to ascertain how well the subcell size corresponds to variations in local terrain.
- 3) The outline of each "grouping" of subcells as selected by the operator is displayed at the time of the "grouping" process. If the "group" is not satisfactory to the operator, it can be deleted and redesignated until the operator is satisfied.
- 4) The operator can limit the stereo model area for which subcell bounds and previously collected DEM points can be displayed by use of a graphics display window. This window is interactively drawn three-dimensionally and has the additional characteristic of determining the elevation at which subcell bounds and group bounds are drawn. This allows the operator to "raise" or "lower"

group and subcell bounds relative to the stereo model surface for purposes of relieving the visual conflict of graphics drawn substantially "higher" or "lower" than the stereo model.

- 5) The operator limits the stereo model area for which DEM information will be collected during a particular collection session by using a "collection window". This limiting area outline is drawn three-dimensionally at the elevation determined by the operator.

DEM measured point information display is performed in two ways:

- 1) Any previously collected information corresponding to the portion of the study areas as contained in the operator's current stereo model can be displayed. This allows the operator to limit the amount of redundant information collection and optimize the systematic collection of DEM information for the study area.
- 2) During a collection session, each point as it is measured is superimposed three-dimensionally on the stereo model. This allows the operator to instantly identify points deviating from the model surface, thus reducing the chance of operator error or machine induced "spikes" that may occur during a collection session.

Project Status. Project status is reported to the operator with a hard copy report. This report is a listing of all incomplete subcells in the project study area. The report also shows the geographic location of each incomplete subcell and the stereo models that the subcell falls on. The status of a particular area of the project may also be ascertained by displaying previously collected DEM information with stereo graphics superposition.

FUTURE ENHANCEMENTS

Two major future enhancements are currently under consideration for implementation on the CAPIR DEM system. These enhancements are: 1) patch adjustment and 2) DEM data densification. Patch adjustment refers to the procedure whereby systematic errors introduced during the collection process are eliminated and random measurement errors are minimized so as to achieve optimum smoothness between adjacent DEM patches and closeness to the figure of the earth. This "vertical leveling" of the patches is analogous to the leveling of stereo models during an analytical photogrammetric block adjustment.

For patch adjustment, the patch is represented as the surface defined by member elevation posts. The surface can be shifted, rotated and twisted with respect to other surfaces. The specific parametric values involved in the adjustment are vertical shift (Z), horizontal shift (X,Y),

rotations about the X and Y axis and a twist (XY term). An absolute orientation procedure, involving known control points from aerotriangulation, is performed upon completion of each model setup. The absolute orientation procedure will validate the results of the model setup function, and the resulting parametric values can be used to correct for systematic biases introduced during model setup.

The adjustment consists of "fine tuning" the smoothness between patches. This is accomplished through capturing redundant observations of posts in overlapping regions along patch borders. These observations are then used to enforce a series of conditions which have the net affect of minimizing elevation discrepancies along the borders. This step in the adjustment procedure can be performed using a simultaneous method, which involves all patches, or a sequential method, which is performed as each patch is collected.

Densification is the application of an interpolation process upon the collected DEM data that produces DEM information at a higher density than was originally collected over the entire DEM project area. For the form in which it will be first implemented there will be a major constraint enforced on the densification process: the "target" or final density will be limited to be the highest collection density (smallest posting distance) value. This means that a DEM collection project having a set of posting values of 5, 10, 15, and 30 meters will only be capable of being densified to the value of 5 meters. This process does not affect the possible implementation subsequent of allowing the original DEM data set to be "densified" to a value other than the aforementioned highest density (smallest posting distance) value.

SUMMARY

The CAPIR DEM system is an effort to more closely meet the requirements of customer digital elevation data compilation. This effort recognized the constraints of time and labor expenditures and the limitations imposed on DEM data accuracy by variations in the abilities of human operators and hardware constraints.

The adaptive spacing grid developed in CAPIR DEM provides a mechanism to appropriately match variations in terrain exhibited by a DEM project area. The DEM data structure easily and logically accommodates the consolidation of data at differing horizontal resolutions to a single set of data at a single resolution. Horizontal sampling resolution can be in units of feet, meters, or arc seconds and DEM Z-values can be in units of feet or meters, allowing DEM output to accommodate a wide variety of customer requirements. Stereo graphics superposition acts as an operator aid and verification mechanism thus reducing the chance of erroneous values in the DEM data base.

Further enhancements to the CAPIR DFM system will continue to address the key issue of responsible balancing of digital data requirements and management of production resources.

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